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INFORMATION PROCESSING FOR TARGET DETECTION AND IDENTIFICATION

A. A. Ksienski

LEVEL II

The Ohio State University

ElectroScience Laboratory

Department of Electrical Engineering
Columbus, Ohio 43212

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This report summarizes the accomplishments attained under the grant. The goal was the development of automatic target classification techniques utilizing low frequency radar returns. Reliable classification techniques were developed and shown to be effective for a large variety of target shapes. In particular a reliable performance has been shown for aircraft identification, where eight classes of combat planes, both American and foreign made, were tested. next page

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20. Abstract continued.

The problem of classifying an object as belonging or not belonging to a specified catalogue of classes was successfully solved and a simple and reliable implementation was devised.

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TABLE OF CONTENTS

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1. SUMMARY OF RESEARCH ACCOMPLISHMENTS

The objective of the investigation performed under this grant was to extend the previous work [1] which demonstrated the appropriateness of low frequency radar returns to the identification of objects of arbitrary geometry. Among the main goals of the study was the search for optimum features and minimization of the dimensionality of the feature vector for representative sets of airborne target classes. The previous studies were restricted to the specific airplanes, MIG19, MIG21, F104 and F4. The most important limitation on the ability to test more classes was the paucity of electromagnetic data available either experimentally or analytically. Computational techniques were developed under this Grant to provide such data and were instrumental in obtaining most of the data used. Thus a substantial effort was expanded in computation of further electromagnetic scattering data for new classes of objects. The major effort in the generation of new data was aimed at increasing not only the number but also the type of classes available for processing and classification. Specifically the scattering characteristics of the following airplanes were computed, MIG23, F14, SR71 and B1. The data set obtained was comprehensive in that the complex scattering matrix was computed for 12 frequencies at an incremental grid of 5° in both θ and ϕ polar coordinates. Thus both polarization and phase parameters were available for optimization. The particular choice of airplane types was motivated by the following considerations. The previously examined airplanes were all of approximately similar size; the particular wing span or fuselage may have differed but the maximum dimensions did not vary by more than 50%. This commonality made the choice of the appropriate frequency range relatively straight-forward. A more complicated situation arises when airplane dimensions vary as much as 300%. The Rayleigh range for one airplane extends well into the resonant range for the other. The problems that arise are not so much the discrimination of a small airplane from a large one but the simultaneous capability of discriminating between several large airplanes as well as between small ones. The further constraint on the system is the requirement of minimum dimensionality. Thus one possible solution might have been to extend the frequency range to accommodate all sizes by increasing the number of frequency samples used. This is prohibited, however, by practical considerations which require the minimization of the number of frequencies. A thorough study was therefore carried out to determine the optimum features for the representation and classification of targets of widely varying sizes in order to minimize the number of frequency features used for classification. In particular the feasibility was investigated of utilizing only two frequencies, and also the performance for a single frequency was assessed. The results have shown that with the utilization of both polarization and phase two frequencies were adequate for the reliable classification of the eight classes considered (MIG19, 21, 23; F104, F4, SR71, B1).

The optimum two frequencies were found by an exhaustive search of all frequency combinations. The errors were shown to be negligible for the overwhelming majority of cases with just a handful of cases resulting in measurable errors for noise environments up to 30% of signal level. The study of the optimum single frequency utilizing both polarization and phase information resulted in not much more degraded performance with over 95% reliability in the presence of noise of up to 20% of signal level [2].

Various aspects of classifier design for the radar target identification as a type of pattern recognition problem have been investigated [3-9]. The classes are characterized by highly convoluted, data surfaces in feature-space. The measured pattern is considered to be a "noisy" version of an "ideal" pattern that lies on one of the data surfaces. The problem of radar aircraft identification has been considered to be an example of such a problem, where the data surfaces are functions of aircraft orientation with respect to the radar. A formulation of the classification problem has been made in terms of Bayes decision theory. This includes statistical models of orientation uncertainty, and uncertainty associated with feature measurements for any given orientation value. Based on this formulation the Bayes classifier for the problem was derived.

Considering the particular case where orientation uncertainty is modeled by a uniform distribution, and feature measurement uncertainty, or "noise", is modeled by a normal distribution, some problems concerning the implementation and evaluation of the Bayes classifier were investigated. These problems included:

(i) efficient computer implementation of the Bayes classifier;

(ii) evaluation of misclassification probability of the Bayes classifier;

(iii) implementation of the Bayes classifier when a parameter of feature measurement uncertainty, viz., standard deviation of the normal distribution, is inexactly determined;

(iv) effect of increasing dimensionality on misclassification probability at individual orientation possibilities;

(v) utilization of the Bayes classifier in a sequential multiple observation procedure.

The Bayes classifier for the problem where class-conditional probability distributions are Gaussian mixtures was first implemented in a practical pattern recognition problem by Sebestyen [10]. Since the nearest-neighbor classifier with reference set corresponding to discrete orientation possibilities has been used with success in the radar aircraft identification problem, properties of the Sebestyen and nearest-neighbor classifiers have been compared.

A relationship between the Sebestyen and nearest-neighbor classifiers has been obtained by showing that the former is obtained when discriminant functions are based on mixtures of distributions, with the mixing being over orientation possibilities, and the latter is obtained when multiple discriminant functions corresponding to each class and orientation possibility are used to determine the sub-class and corresponding class. Conditions on reference pattern configuration for the identity of decision surfaces of the two classifiers have been obtained. Based on these conditions, an algorithm for determining the identity of decision surfaces was derived.

The Sebestyen and nearest-neighbor classifiers were compared in terms of standard classifier evaluation criteria, viz., misclassification probability and computational economy, and in terms of criteria which were thought to be appropriate for radar aircraft identification, viz., extensibility of the classifier to the multiple observation problem, and classifier robustness. Misclassification probability, classfication bias, and robustness were experimentally compared with multivariate data from the radar aircraft identification problem. Comparison of computational economy was made in terms of number of computation steps, and computation time on a typical general purpose computer.

A problem that received substantial attention was the determination of whether an observed object is or is not a member of the listed or catalogued classes for which the classifier is designed. The problem is of importance in many areas where the catalogue is not exhaustive, in particular in aircraft identification it cannot be exhaustive, and in fact the smaller the list of alternatives the better the classification performance. The difficulty with solving the problem is, of course, the lack of information regarding the unlisted or unexpected objects. An approach was used, therefore, that utilizes only information regarding the listed classes. The technique developed still aims at minimizing the probability of error in the identification process. Since no information regarding the unlisted objects is available, instead of minimizing the overall probability of misclassification the method prefixes the probability of misclassifying a listed object as an unlisted one and minimizes the region in feature space associated with the listed class. This minimizes the likelihood of misclassifying unlisted objects as listed ones.

It was proved that the devised classifier could be implemented as a threshold test. The use of the latter greatly simplifies the design of the classifier. The classifier was applied to an aircraft identification problem. It was shown that the error probability of misclassifying catalogued targets as uncatalogued and vice versa can be made very small, while keeping a high probability of correct identification of the listed objects when they are present. The misclassification probability for several specific cases was computed and was found to approach zero when the number of the features used was as low as four. The additional step of discriminating listed objects from unlisted ones produced very little degradation of the overall classification performance. The overall misclassification probability for all cases considered was changed less than five percent. The implementation of the developed scheme was shown to be simple and efficient [11].

An interesting area of classification involving a new potential set of electromagnetic features attracted the recent attention and effort of numerous investigators. This endeavor is referred to as RADAM - Radar Detection of Agitated Metals. A considerable amount of data was gathered by the Air Force and the Army on the modulation of radar signals produced by moving scatterers such as tanks, troop carriers and trucks. The effects referred to are in addition to the main doppler line (skin line) corresponding to the vehicle's relative motion with respect to the illuminating radar. The questions raised with regard to the generated spectra relate to their origin and their usefulness as target signatures. The second question is, of course, partly related to the first in that the origin of the modulation may determine in large measure its variability with different targets and its invariance for a given target as a function of time, target orientation and target condition. The other aspect of usefuless relates to the level of the modulation signal which would ultimately determine the maximum obtainable signal-to-noise and signal-to-clutter ratios. The Radam effects were subdivided into two main categories; those due to the motion of the component parts of the object such as the track of a tank or wheels of a truck, and the so-called, junction effects where metal parts are joined together nonrigidly such as by screws or rivets (in contrast to welds). The junction effect stirred considerable controversy, with some experimenters denying its existence as an experimentally detectable phenomenon [12] (claiming its level to be no more than 60 dB below the skin line) and others contending that the signal level is no less than 20 dB below skin line [13]. An analysis was therefore undertaken of the phenomenon. Since a junction is produced by adjacent sheets of metal, or plates, with a separation distance depending on the tightness with which they are joined, it appeared that a reasonable electromagnetic model for the junction would be a metal plate with a gap at its center. The gap size could assume various values from zero up to any finite size. An analysis of the scattering cross section of such a plate has shown that it could indeed vary by orders of magnitude depending on whether the gap is closed or open. The amount of variation was shown to be strongly dependent on the radar frequency. At frequencies where the plate size was less than half a wavelength a gap produced a very large drop in radar cross section; for plate sizes between a half wavelength and a wavelength the gap actually increased the cross section; while for plates of several wavelength in size the gap did not significantly affect the radar cross section. This analysis explained the source of the controversy. The experimenters that did not detect a significant junction effect were operating at relatively high frequencies, i.e., in the gigahertz band, and in particular x-band, where vehicle components would be substantially larger than a wavelength, while those that claimed a significant junction effect operated in the lower, MHz range (VHF-UHF). Although the frequency dependence of the junction phenomenon seems to have been explained the exact origin of the modulation and its dependence on target type has not. The same consideration applies to a large extent to the spectra produced by the moving components. It is clear that such movement would produce various spectral lines in a given frequency range. It is thus apparent that a track of a tank would produce returns at a spectral range between zero doppler and twice the skin line doppler, but the shape of that spectrum can be determined only by analyzing the scattering properties of the track in motion.

An analytical and computational effort was made to determine the scattering frequency response at high frequencies of both tracks as well as the basic driving devices of tracded vehicles. The relevant spectra were obtained and published [14-16].

The study of the junction phenomenon at low frequencies (VHF-UHF) is continuing under a study sponsored by the Avionics laboratory of the Air Force.

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